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Voltage Sag Immunizer for AC Contactors

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(Abstract) Power grid disturbances, mainly voltage sags, which sometimes last less than a fraction of second, can cause a plant to shut down and interrupt production for considerable periods of time, which leads to loss of production and high costs. AC contactors are a safe, easy and cheap way to control electric loads. AC contactors provide a remote switch between electric motors and the power grid that supplies them. AC contactors are more vulnerable to voltage sags, than the motors they control. Often, the AC contactor is forced to open when a short voltage sag occurs and as a result the motor stops, whereas the motor alone, due to its inertia, could withstand this voltage sag. This article describes an electronic device that enables AC contactors to ride through power quality disturbances. The proposed device is connected to the contactor coil and consists of a power conversion excitation and hold-in circuit, a control circuit, an immunity circuit and a shutdown circuit. It does not disturb contactor operation, is easy to use and can be built from cheap, commercially available components. Experimental tests have demonstrated the effectiveness of the proposed electronic device for improving the immunity of AC contactors during voltage sags.

Keywords: AC Contactor; Power Quality; Voltage Sags; Immunity.

1. Introduction

Power quality disturbances create major problems in continuous process industries. Momentary interruptions, voltage sags and dropouts are some of the most serious power quality problems faced by industrial customers [1-4]. Power grid disturbances, which sometimes last less than a fraction of second, can cause a plant to shut down and interrupt production for considerable periods of time, which leads to loss of production and high costs [5, 6]. Most of these disturbances (92-98%) are voltage sags that occur due to lightning strikes, accidents, squirrels or equipment failure on the transmission and distribution grid feeding the plant. Voltage sags (also known as “voltage dips”) are short-duration reductions in voltage magnitude. Their duration is typically between a few cycles of the power system frequency and a few seconds.

Most of them are of short duration (1-6 cycles), corresponding to the clearing time of upstream utility protective equipment. Due to industrial equipment reacts to voltage sags in a variety of ways, there is not a unique solution to protect them. In some cases, the best solution is to protect the entire plant from voltage sag with a device such as a dynamic voltage restorer [7]. In other cases it is better and even more economical to identify particularly susceptible components and protect them alone.

An AC contactor is an electrically controlled switch that uses a solenoid to close one or more pairs of electrical contacts when an appropriate AC voltage is applied to the coil of the solenoid. The solenoid consists of an electromagnet that attracts a moveable bar. The electric contacts are attached to the movable bar or armature that is spring loaded so as to cause the armature to move away from the electromagnet when there is no electric signal on the coil. When an appropriate voltage is applied to the coil, the magnetic flux crossing the electromagnet and the armature provides an attractive force that overcomes the spring tension, moves the armature and closes the contacts. AC contactors are often used to provide a remote switch between electric motors and the power grid that supplies them. Although electric motors can ride through some voltage sags [8], AC contactors are extremely sensitive to this type of disturbances [9]. This weakness of AC contactors can cause the unnecessary interruption of industrial process resulting in important economical losses. Many devices that are able to mitigate such problem have therefore been proposed. Most of these provide a momentary ridethrough capability by maintaining the AC contactor in the closed position, by means of various procedures, so that the electric motor or the electric load remains connected to the grid when a power disturbance occurs in the power supply.

Different devices with AC/DC conversion are known to regulate the voltage applied to the coil of an electromagnet and specially that of a contactor in order to get it closed in a controlled manner to reduce the bounce of the contacts, and to energize and de-energize the contactor coil quickly [10,11]. Power supplies with AC/DC conversion have been proposed, including a capacitor connected in parallel with a maintenance coil added to the contactor, in order to provide a slight delay in the separation of the contacts in front any power disturbance of the network [12]. It has been described a method and an apparatus to improve the characteristics of devices with AC solenoid during disturbances in the quality of supply. This device is configured to superimpose a DC component to the AC signal provided by the AC source and give to the output, at

least a part of the AC signal modified by the DC component through the coil [13]. The voltage regulator for contactor ride-through proposed by Kelley et al. [14, 15] is connected to the contactor coil and consists of a rectifier and a buck converter, DC-to-DC power converter. This power converter controls that the voltage at the contactor coil remains constant even in front significant voltage drops. The device has a capacitor for energy storage. When voltage sags occur, the contactor coil is fed through the previously charged capacitor to ensure the operation of the contactor. The device has a delay in the operation of the contactor, so if it has to be open immediately, an emergency stop button it is required. This article presents an electronic device for improving the immunity of AC contactors during power quality disturbances; particularly voltage sags [16, 17] with new features. The proposed electronic device, shown in Figure 1, is connected to the contactor coil and consists of several circuits. Each of these circuits has a defined task and is supplied at a set voltage level. Some of them, such as the *power conversion, excitation and hold-in circuit* and the *shutdown circuit*, must safeguard the normal operation of the AC. The *immunity circuit* supplies the contactor coil when a disturbance occurs and is able to maintain contactor operation for a certain period of time, often for the entire duration of the disturbance. Finally, *the control circuit* decides which circuit must be activated at each moment. The paper is organized as follows. Section 2 describes the proposed electronic device and explains how it works. Section 3, validates the effectiveness of the electronic device through a series of experimental tests. Finally, Section 4 presents the conclusions drawn from this research.

2. Device Description

An AC contactor is operated by applying a voltage to the electromagnetic coil, which generates a current that induces a magnetic field to close the electrical contacts. AC contactors require a high current to close the contacts initially and a relatively low current to hold them closed during normal operation. Once the voltage is removed from the coil, the spring causes the contacts to open. Therefore, in AC contactors three different operational states may be distinguished: the *excitation state*, in which a high current is required to overcome the spring force; the *hold-in state*, in which a low current is all that is required to keep the contacts closed; and the *shutdown state*, in which the voltage in the contactor coil is removed by voluntary action and as a result the contacts open. AC contactors are more vulnerable to power quality disturbances than the motors they control. Often, the AC contactor is forced to open when a short voltage sag occurs and as a result the motor stops, whereas the motor alone, due to its inertia, could withstand this voltage sag. In order to overcome this problem an electronic device for improving the immunity of AC contactors during power quality disturbances is presented.

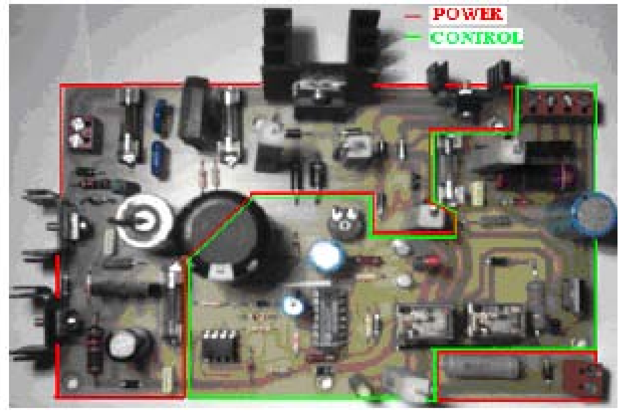

Fig.1. Photograph of the proposed electronic device for AC contactor ride-through

The proposed device do not disturb the normal contactor operation but adds a new operational state to the AC contactor, the *immunity state*, in which the contactor coil is supply by an energy storage device when a power quality disturbance occurs in the AC voltage source. One of the most relevant features of the proposed electronic device together with an AC contactor is that every one of its operational states is associated with a circuit and every circuit is powered at a different voltage level through linear voltage regulators. The device consists of a *power conversion, excitation and hold-in circuit*, an *immunity circuit*, a *control circuit* and a *shutdown circuit*. Figure 2 shows a block diagram of the electronic device, in which the various circuits can be distinguished.

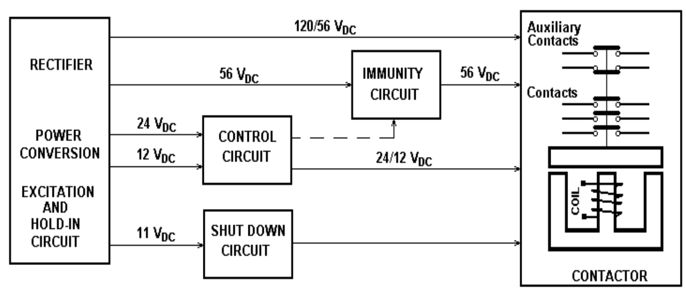

Fig. 2. General block diagram of the proposed electronic device showing the different circuits that form the device

The power conversion, excitation and hold-in circuit includes a rectifier that is used to obtain a DC input voltage from the AC supply voltage and five linear voltage regulators that provide various DC voltage levels (120 V, 56 V, 24 V, 12 V and 11 V). Although a contactor is designed to operate on an AC voltage source, it can work equally well on a low DC voltage, as stated in [17]. Each of these voltages is appropriate for a specific contactor state, i.e., 120 V and 56 V are suitable for closing the contacts by overcoming the spring tension, 24 V is the voltage that produces the current needed to keep the contacts closed, 12 V is the voltage required by two ICs (NE5532P and HEF4001BP) in the *control circuit* and 11 V is the voltage required by the *shutdown circuit*. The *control circuit* automatically provides the correct voltage according to the state of the contactor at any given time. The *immunity circuit* includes an energy storage device, that is, a capacitor

that is always loaded. When a disturbance occurs in the AC voltage source the immunity circuit is activated by the control circuit and supplies the contactor coil. It is able to maintain the contacts closed for a period of time that depends on the time constant of the first order circuit which is formed by the resistance of the contactor coil and the capacitance of the storage capacitor.

The shutdown circuit ensures that the contactor can be interrupted without delay when this is required by a voluntary action. This circuit is composed of a rectifier circuit, a voltage stabilizer and a static switch to unload the capacitor of the immunity circuit in cooperation with the control circuit.

Figure 3 illustrates the behavior and associated voltages of the circuits, with the exception of the *shutdown circuit*. This figure shows the operational states-including the response to disturbances—of a contactor with the proposed electronic device, where the gray waveform is the voltage in the contactor coil and the black waveform is the voltage at the main contacts (15 V DC in this case)—a test signal that indicates whether the contacts are open or closed.

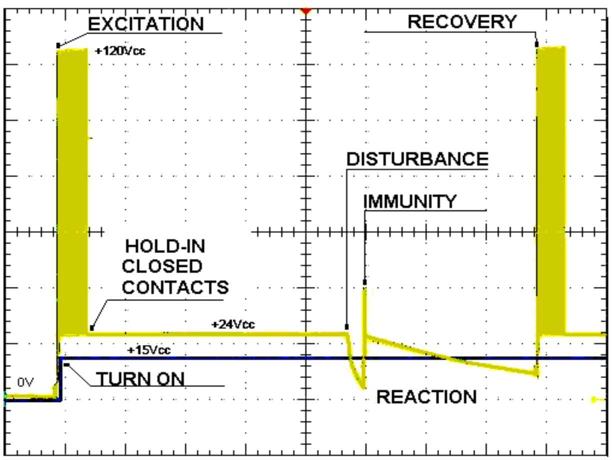

Fig 3. Operational behavior of the electronic device

The complete circuit of the proposed electronic device is shown in Figure 4, where the before mentioned circuits can easily be distinguished. This device is designed to be used in any type of contactor, even D.C. contactors, and is assembled using cheap, commercially available components. The connection of the electronic device to the contactor coil is depicted in Figure 5.

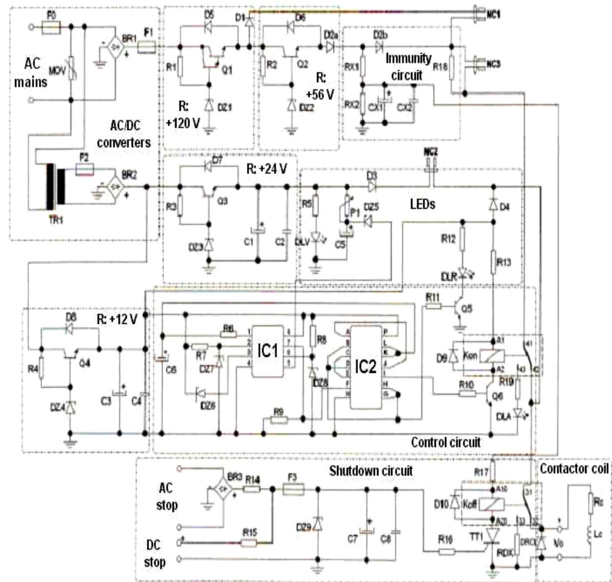

Fig. 4. Complete circuit of the electronic device

Supply voltage is selected inserting a jumper in the jumper pins NC1, NC2 and NC3 according table 1. It is important to point out that in the shutdown circuit the supply voltage of this particular circuit can be AC voltage or DC voltage depending on the input voltage.

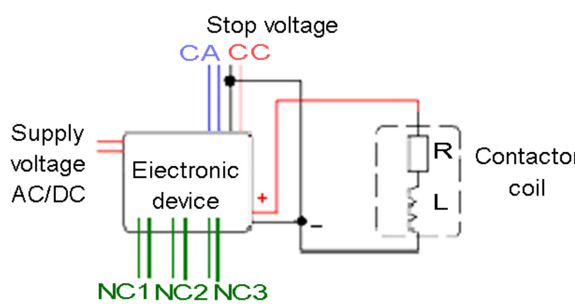

Fig.5. Connection of electronic device to the contactor coil

Table 1.- Supply voltage selection according disposition of jumpers in the jumper pins NC1, NC2, NC3

Voltage	NC1	NC2	NC3
230V and 120V C.A.	ON	ON	ON
42V C.C.	OFF	ON	ON /OFF
24V C.C.	OFF	ON	ON
12V C.C	OFF	OFF	OFF

3. Experimental Results

The electronic device was tested in a setup (Fig. 6) in which a DC machine (separately excited) acting as a load was driven by a single-phase induction motor connected to a voltage sag generator through an AC contactor (Sirius 3RTT1025 1A 0 Siemens).

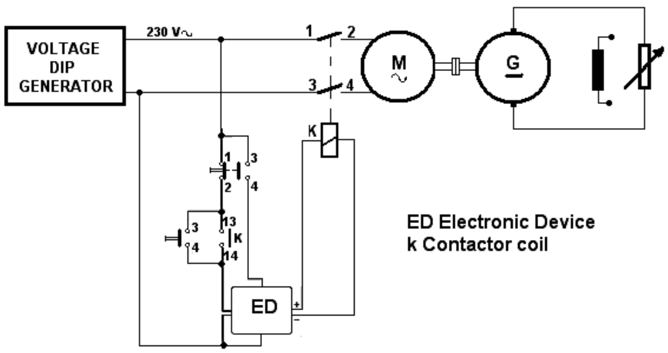

Fig. 6. Test setup, showing the proposed electronic device (ED) connection

The operation waveforms were recorded using a four channels digital oscilloscope (Tektronix TDS5034B). The response of several variables (motor current, speed, AC supply voltage, and contactor coil voltage) to a short voltage sag when the proposed electronic device was not used is shown in Figure. 7. In this case, as a consequence of the voltage sag (100 ms), the contacts of the contactor are opened and the motor stops the process it drives and then the AC contactor must be manually restarted.

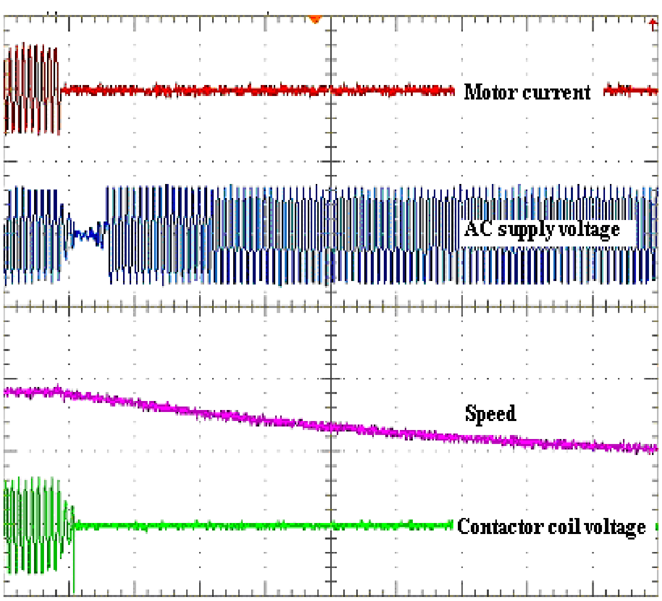

Fig.7. Operational waveforms of an AC contactor, without the proposed electronic device, during a short voltage sag (100 ms).

The responses of these variables to similar voltage sag (120ms) when the AC contactor was connected to the power supply via the proposed electronic device can be seen in Figure 8.

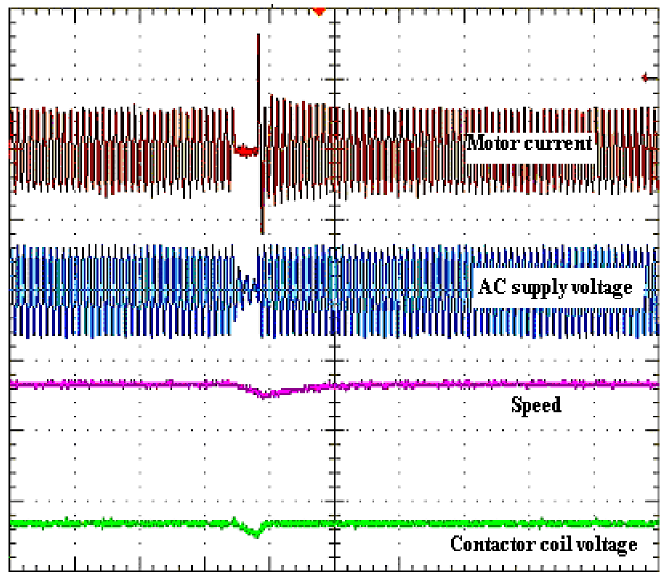

Fig.8. Operation waveforms of an AC contactor, using the proposed electronic device, during a short voltage sag (120 ms).

In these circumstances, despite the voltage sag, the motor is kept running and only a slight disturbance in its speed is appreciated. It should be point out that a small transient torque is also observed but it is not shown in the waveforms of Figure 7. Waveforms corresponding to the same variables, as in Figure 8, except that in this case the voltage sag lasts longer (1.12 s), are depicted in Figure 9.

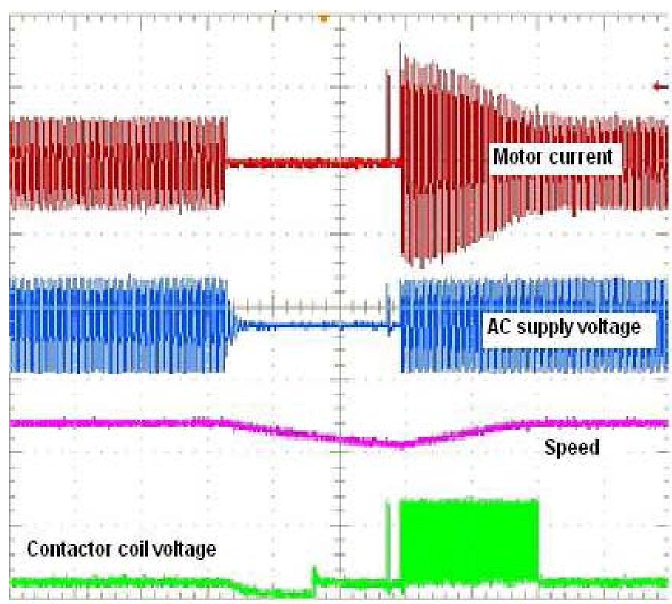

Fig.9. Operational waveforms of an AC contactor, using the proposed electronic device, during a long voltage sag (1.12 s)

In these circumstances, the voltage sag may cause the motor to stop. Nevertheless, it can clearly be observed that the action of the immunity circuit allows the main contacts to remain closed. The motor keeps running but there is a significant drop in its speed (throughout the voltage sag time and its recovery time). These experimental results show that using the proposed electronic device, the AC contactor improves its immunity to

power quality disturbances such as voltage sags and voltage drops, which prevents loss of production in industrial plants.

4. Conclusions

This article presents an electronic device that allows an AC contactor to ride through power quality disturbances, in particular voltage sags. The proposed electronic device consists of several circuits (a power conversion excitation and hold-in circuit, a control circuit, an immunity circuit and a shutdown circuit), each of these circuits has a defined task and is supplied at a set voltage level. The electronic device is connected to the contactor coil and it does not disturb the contactor operation, can be adapted to almost all types of electrical contactor, is easy to use and can be built from cheap, commercially available components. Experimental tests have demonstrated its usefulness in improving the immunity of the AC contactor during voltage sags. The electronic device is a new, simple and economical solution that can mitigate the problems caused by voltage sags in the process of the industrial plants.

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